Microwave and Nanosatellites:

AMSAT's Future in the Microwave Bands

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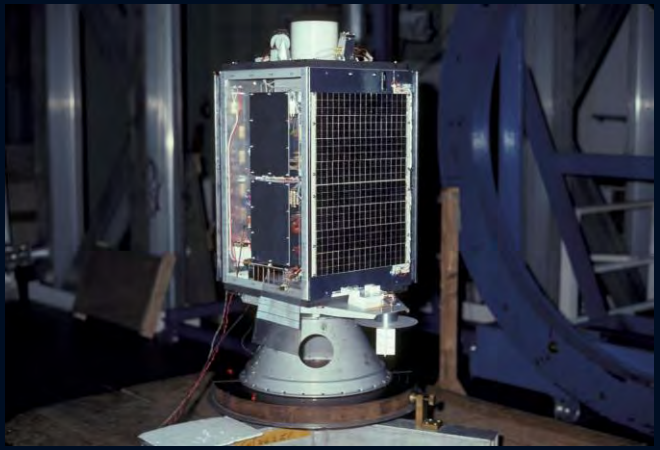
AMSAT

PRESENTED BY TOM SCHUESSLER, N5HYP

A brief history of microwave on AMSAT satellites

AMSAT satellites using microwave bands

- UoSAT-OSCAR 9
- OSCAR 10
- UoSAT-OSCAR 11
- OSCAR 13



UoSat-OSCAR 9
UoSat OSCAR 11 – Beacons on 2.4 GHz and 10.5 GHz

OSCAR 10
OSCAR 13 – Mode L
23cm uplink, 70cm downlink

Photos courtesy of Dr. Robert McGwier, N4HY
https://n4hy.smugmug.com/AMSAT

AMSAT satellite projects launched

- OSCAR 40

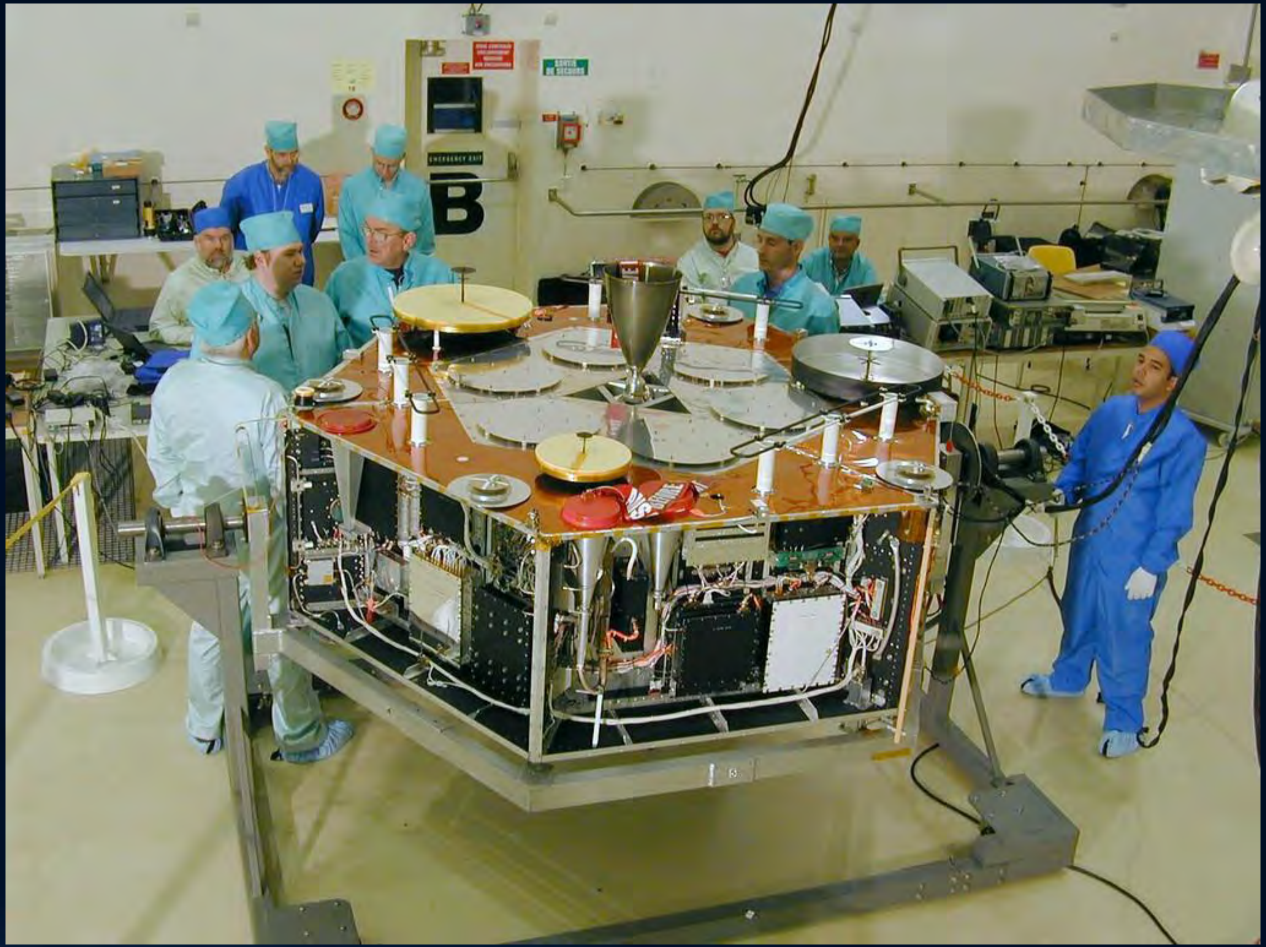


Photo courtesy of Dr. Robert McGwier, N4HY
https://n4hy.smugmug.com/AMSAT

Receivers:
L band
S band
C band

Transmitters:
S band
X band

AMSAT satellite projects launched

Fox-1 CubeSats

- OSCAR 92

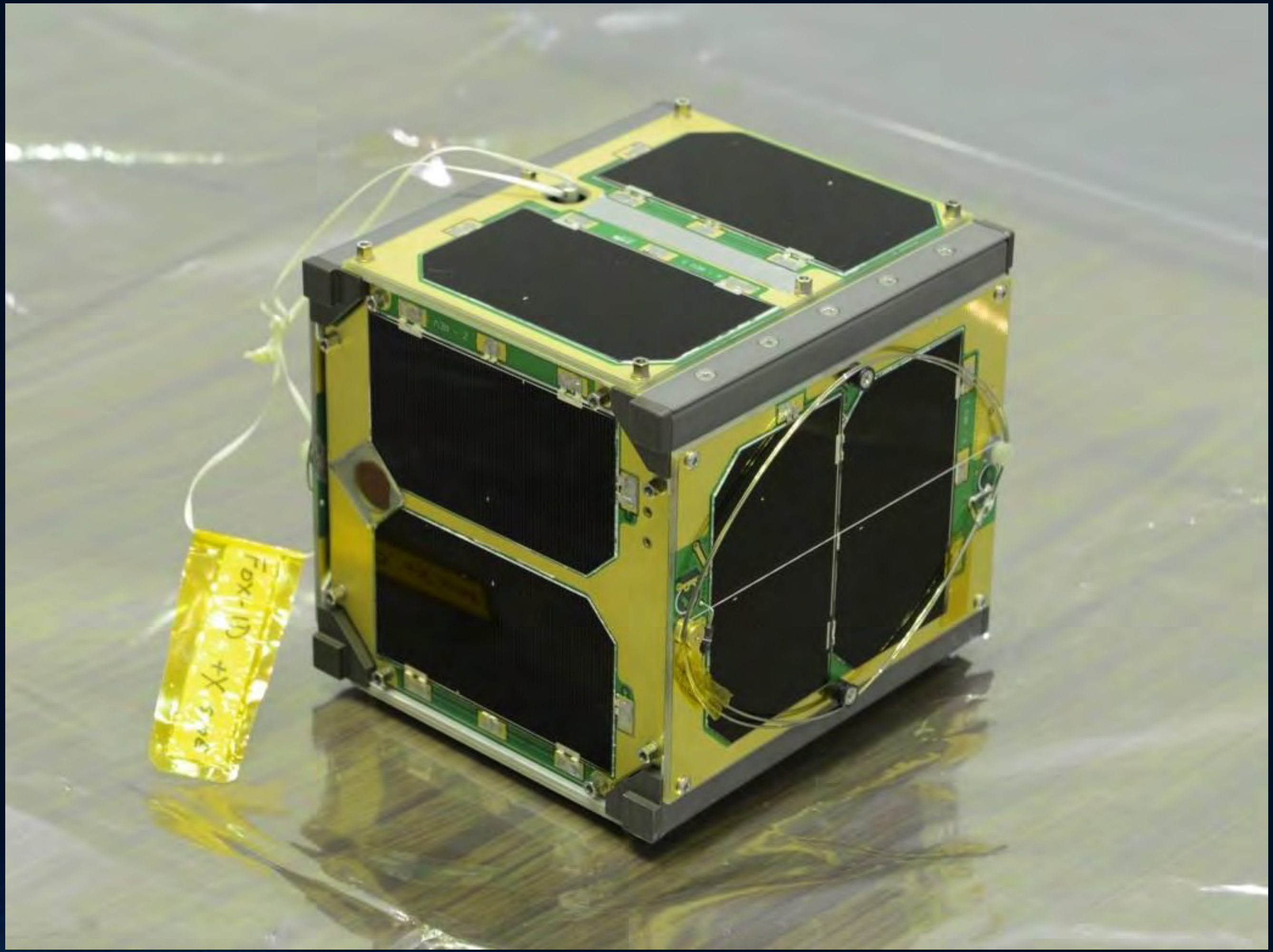


Photo courtesy of me

OSCAR 92 – Mode L
23cm uplink, 70cm downlink

Quick CubeSat Primer

- CubeSat Design Specification
  - Developed by Cal Poly
    - Dimensions
    - Mass
    - Lots more specifics
- Fox-1 CubeSats are 1U
  - U is the designation of size, with 1U being a 10x10x10 cm volume
  - *n*U describes multiples too, 3U and 6U being common sizes
    - Common sizes allows a variety of launch vehicles to carry CubeSats

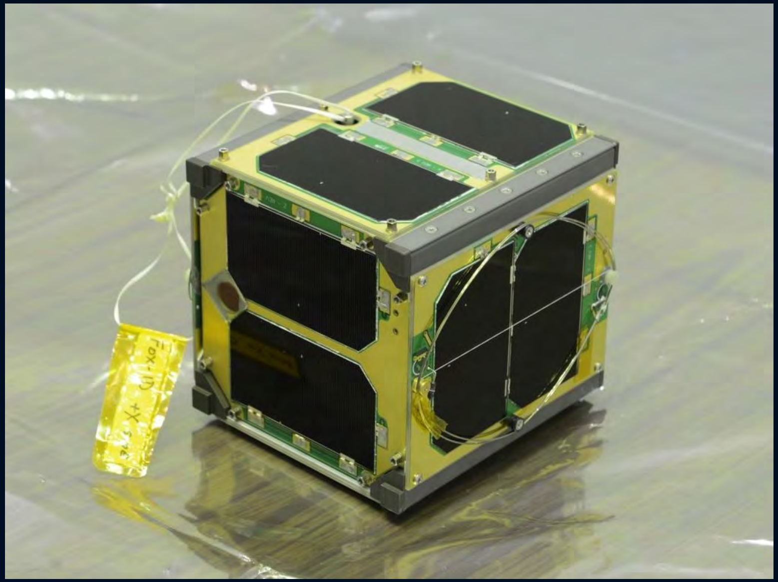


Photo courtesy of me

A bit about AMSAT's "GOLF" Program

GREATER ORBIT; LARGER FOOTPRINT

Return to HEO (Highly Elliptical Orbit) Through Developmental Steps

- Progression of AMSAT's CubeSat capability from LEO (Low Earth Orbit) to HEO orbits
  - Incremental series of satellite projects provides managed risk of increasingly complex missions
- Each mission targets successive steps of development, testing, operations, and learning
  - Hands on knowledge and experience builds team capability for HEO
  - Achieves increasing levels of proficiency for successful missions to higher orbits
  - Each mission itself contributes another satellite to AMSAT's goal of "keeping amateur radio in space"

Return to HEO Through Developmental Steps

- Systems can be purchased
  - AMSAT has partnered with educational and commercial entities to fly developmental systems
    - Lower cost to us, space heritage for them
    - GOLF ADAC (Attitude Determination And Control system) is one such partnership*
  - Space qualified systems can be very expensive
    - Generally, less risk = higher cost
  - Commercial systems are proprietary
    - Hardware with a manual in six languages
    - No chance to learn the system functions to enhance our capability*
      - Troubleshooting, enhancements, knowledge base

* GOLF ADAC provides opportunity to learn and co-develop
(more than just a manual in six languages)

Return to HEO Through Developmental Steps

- Series of 3U starting simple, incrementing
  - GOLF-TEE (Technology Exploration Environment) *LEO*
    - ADAC
    - Deployable solar panels
    - Microwave
    - SDR
    - Radiation tolerant IHU design
  - GOLF-1 *LEO*
    - Lessons learned from GOLF-TEE
    - More SDR features/bands
    - Educational STEM experiments
  - GOLF-*n*
    - Continue to develop and prove technology to reach HEO
    - Target higher orbits

Microwave on GOLF satellites

First “Five and Dime” birds in the works

5 GHZ UPLINK, 10 GHZ DOWNLINK

Why is it referred to as "Five and Dime"?

- It is a clue to my age in case you thought I was only in my thirties

  (We had both a Kresge's and a Woolworth's in Iowa City)

- I floated it a few times in meetings and it took off
  - Anything that "takes off" in the AMSAT biz is considered good!

"**Five and dime** (also known as five-cent stores, dime stores, and ten-cent stores) is a type of store that was popular in the United States in the early to mid-20th century. They sold many different items, most of which were worth five or ten cents."

- *Wikipedia*

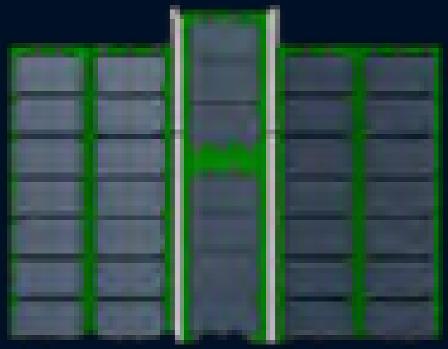
"Five and Dime"
Origin of the frequency/band choices

- Selected by AMSAT Engineering team for Heimdallr satellite (partnership entry for NASA Cube Quest Challenge)
  - Readily available components
    - Lower cost
  - Large spectrum available in both bands
  - 10 GHz less susceptible to weather (rain fade) than higher bands

My plan for "Five and Dime":
The new paradigm for AMSAT satellites

- VHF/UHF is crowded!
  - VHF/UHF gain antennas are very large on CubeSats

VHF/UHF gain antennas are very large on CubeSats



"Five and Dime"
New paradigm for AMSAT satellites

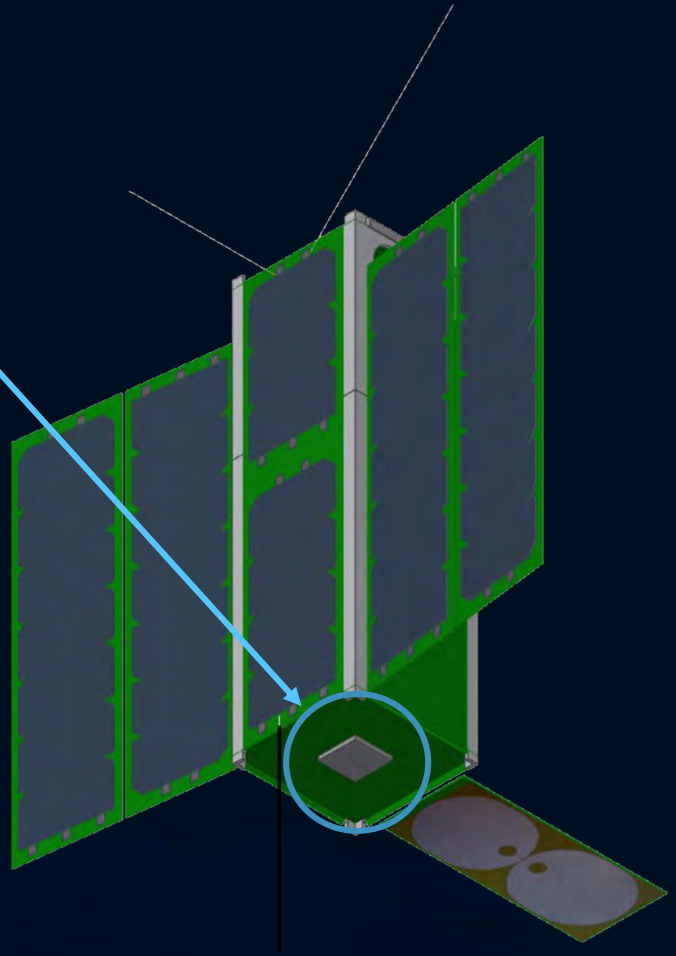
- VHF/UHF is crowded!
  - VHF/UHF gain antennas are very large on CubeSats
- It becomes the baseline mode (i.e. C/x) for future satellites
  - Replaces VHU/UHF "standard"
  - 5GHz uplink / 10GHz downlink
  - Results in common baseline bands for user ground stations
    - One ground station investment useful on all/many satellites (like VHF/UHF today)

Microwave on GOLF satellites:
Modulation types

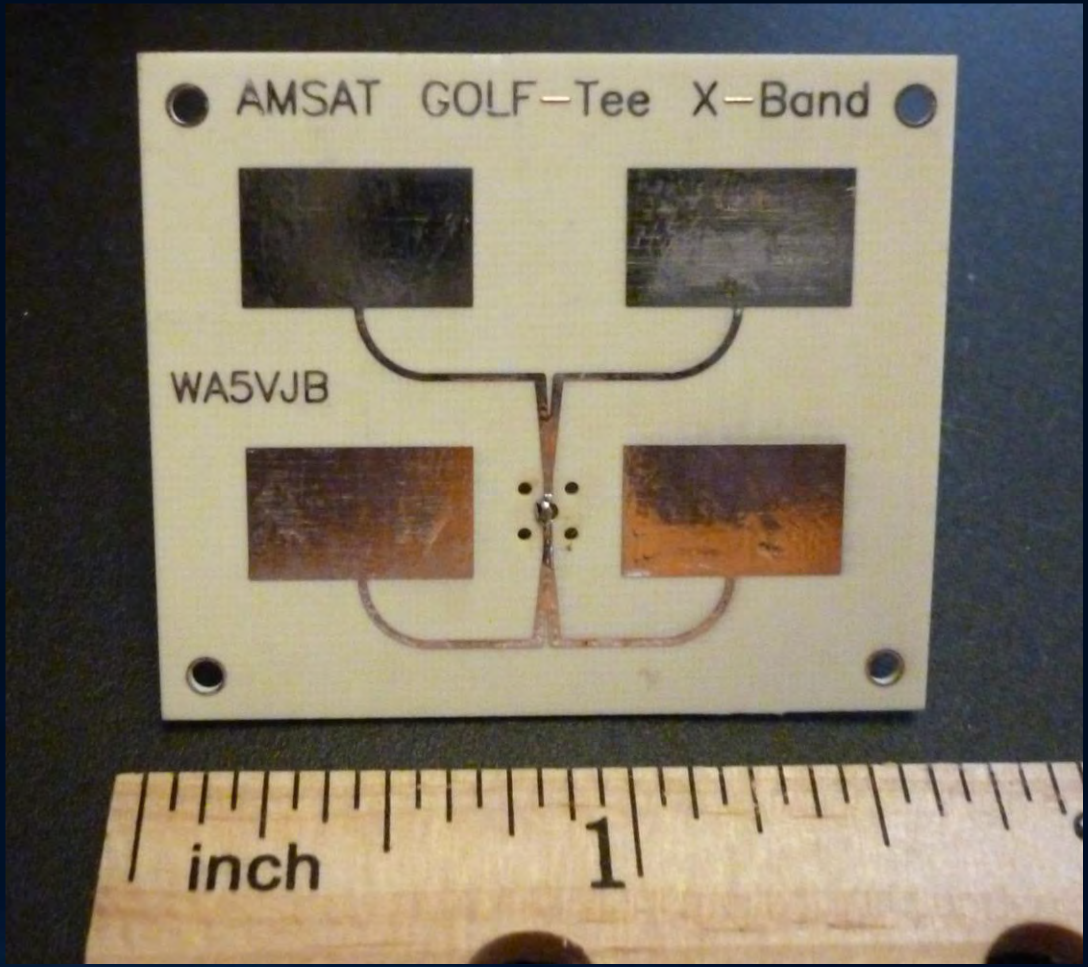
- Both analog and digital
  - Users are our customers! Must consider usage vs. cost
  - DVB-S2 offers good options for high orbits
- Opportunities to experiment
  - SDR enables various modes and combinations
- Satellite power budget plays important part in radios/SDR capability

Microwave on GOLF satellites: GOLF-TEE and GOLF-1

- X band downlink patch antenna
  - (10 GHz) downlink, high speed telemetry demonstration
  - Other capabilities (shown in upcoming slides)

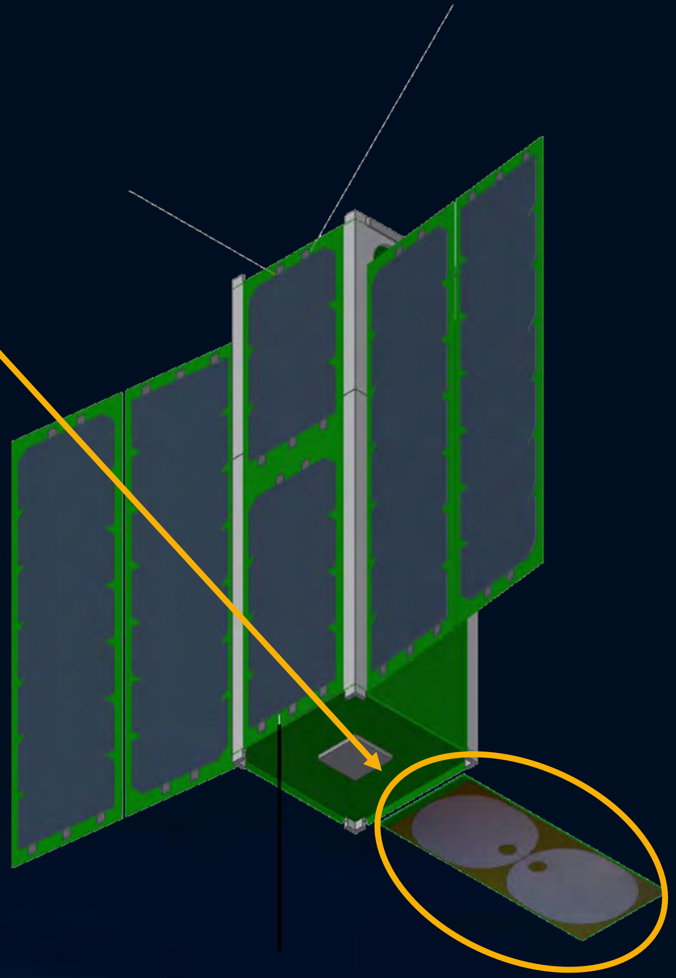


X Band
Downlink Antenna (prototype)

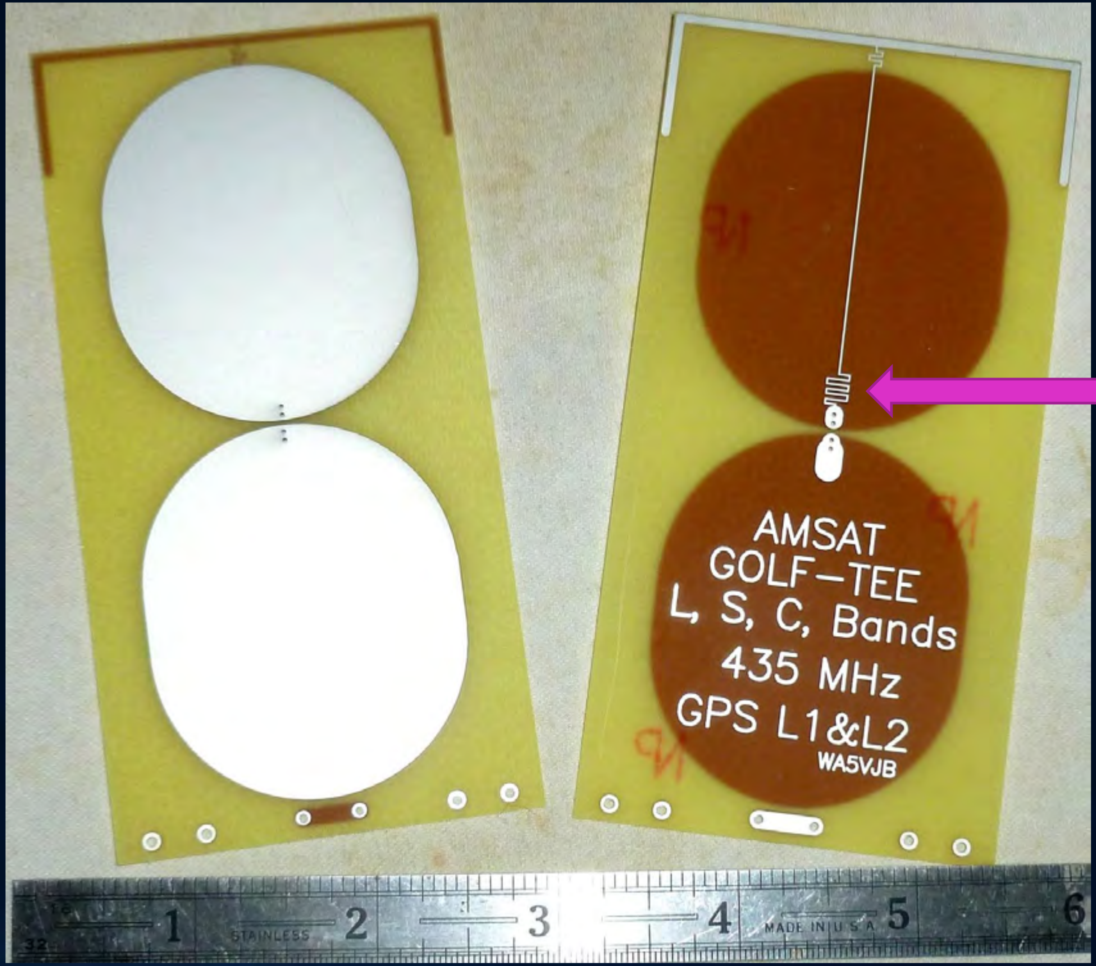


Microwave on GOLF satellites:
GOLF-TEE and GOLF-1

- Multiband uplink patch antenna
  - L band (1.2 GHz)
  - S band (2.4 GHz)
  - C band (5 GHz)

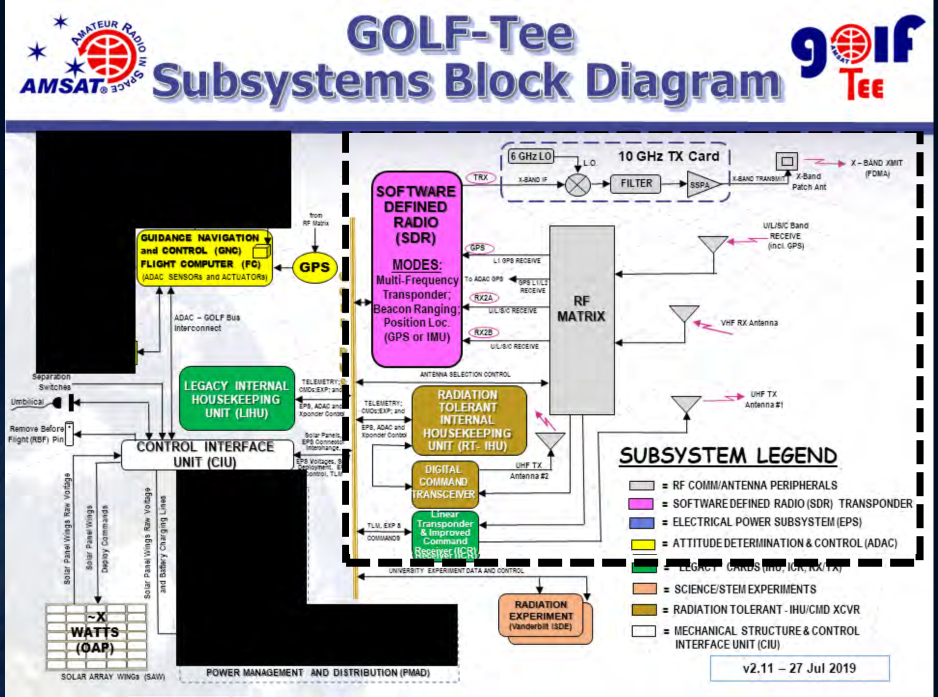


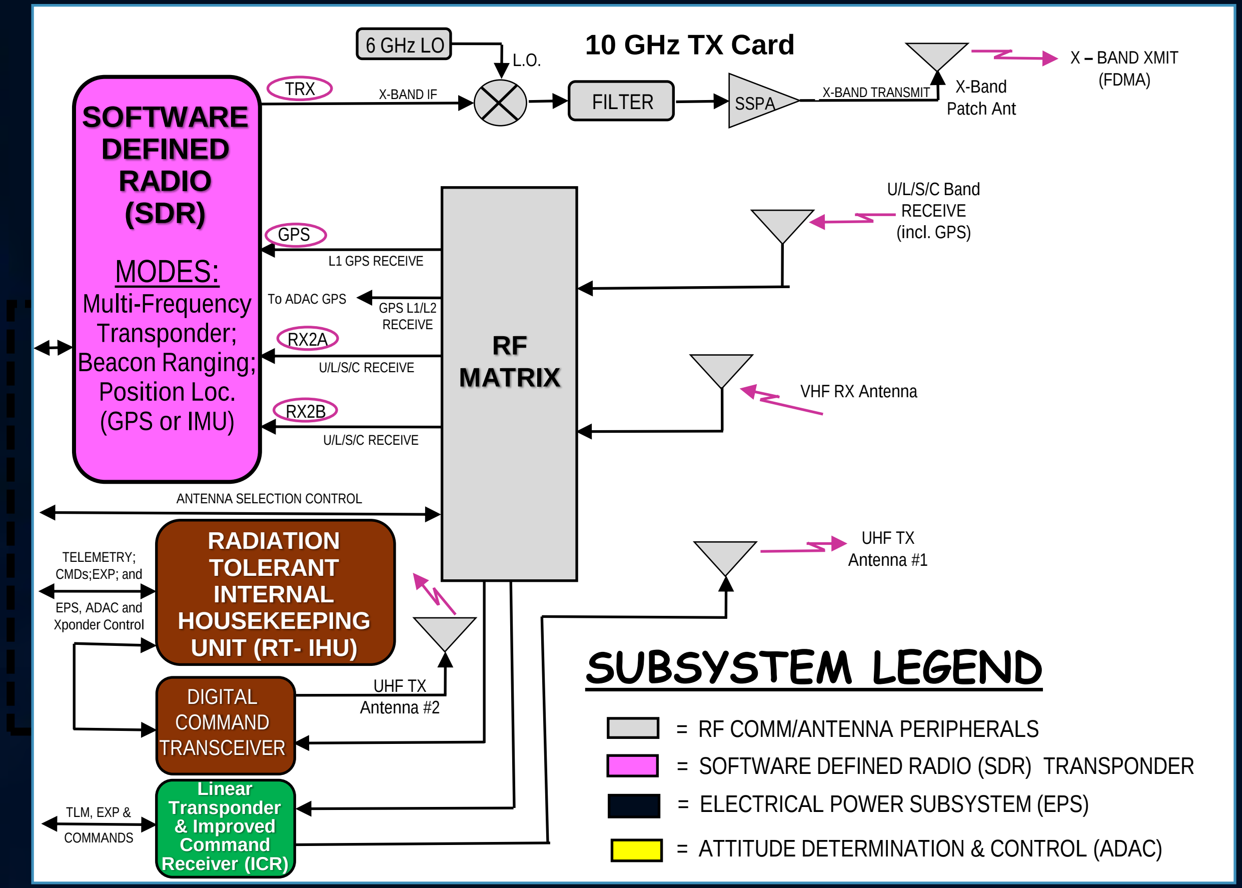
L, S, C Bands including GPS Uplink Antenna (prototype)



UHF "pick" antenna
for V/x mode
(see upcoming slides)

GOLF-TEE
RF Matrix




10 GHz TX Card
6 GHz LO
L.O.
TRX
X-BAND IF
FILTER
SSPA
X-BAND TRANSMIT
X-Band Patch Ant
X – BAND XMIT (FDMA)
SOFTWARE DEFINED RADIO (SDR)
MODES:
Multi-Frequency Transponder; Beacon Ranging; Position Loc. (GPS or IMU)
GPS
L1 GPS RECEIVE
To ADAC GPS
GPS L1/L2 RECEIVE
RX2A
U/L/S/C RECEIVE
RX2B
U/L/S/C RECEIVE
RF MATRIX
U/L/S/C Band RECEIVE (incl. GPS)
VHF RX Antenna
ANTENNA SELECTION CONTROL
UHF TX Antenna #1
TELEMETRY; CMDs;EXP; and EPS, ADAC and Xponder Control
RADIATION TOLERANT INTERNAL HOUSEKEEPING UNIT (RT- IHU)
UHF TX Antenna #2
DIGITAL COMMAND TRANSCEIVER
TLM, EXP & COMMANDS
Linear Transponder & Improved Command Receiver (ICR)
SUBSYSTEM LEGEND
= RF COMM/ANTENNA PERIPHERALS
= SOFTWARE DEFINED RADIO (SDR) TRANSPONDER
= ELECTRICAL POWER SUBSYSTEM (EPS)
= ATTITUDE DETERMINATION & CONTROL (ADAC)

Microwave on GOLF satellites:
Development

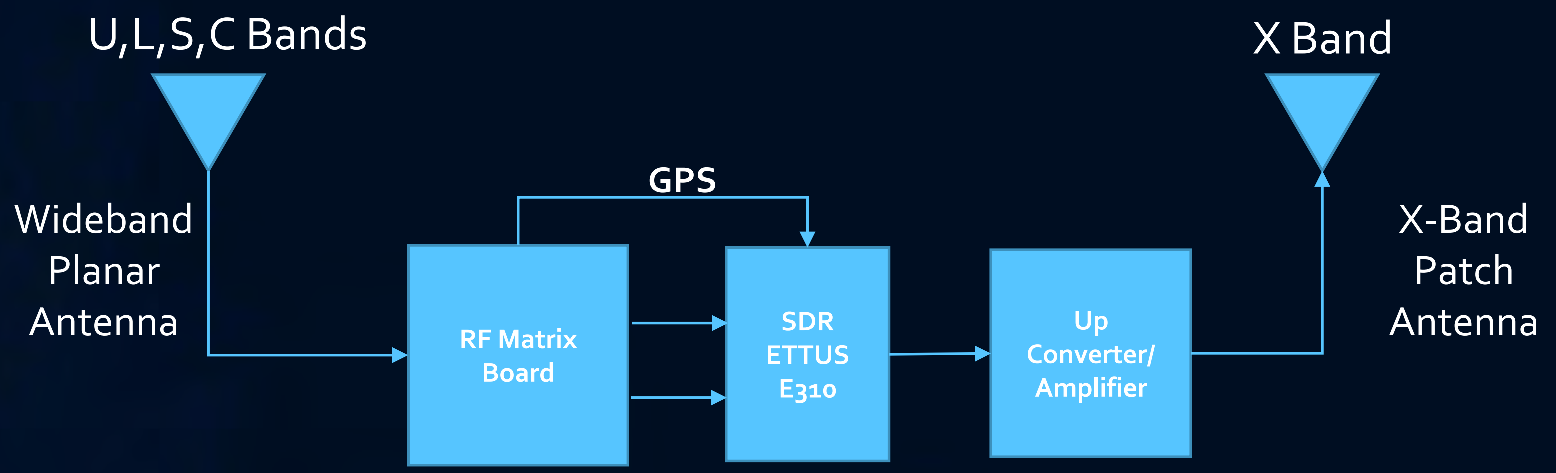
- GOLF-TEE using commercial SDR
  - Ettus E-310 modified
  - Experimental step
  - Alternatives commercially available
  - Designing our own may be better
- Need to develop experienced pool
  - FPGA design
  - FPGA programming

Microwave on GOLF satellites:
Development

"SDR Setup Between Tests"
Photo by Ray Roberge, WA1CYB

Microwave on GOLF satellites:
SDR Design (GOLF-TEE)

Output design minimum target 27 dBm, optimal ≥ 30 dBm



Ray

WA1CYB

Microwave on GOLF satellites:

GOLF-TEE SDR Operation

- SDR capability beyond high speed beacon is present, as part of the overall GOLF-n development
- May be used depending on progress of primary *CSLI* mission goals*
  - *ADAC*
  - *Deployable solar panels*
  - *Radiation tolerant IHU design*
  - ***SDR microwave X band beacon***
- Mode V/x "virtual" transponder most likely possibility
  - SDR receives and repeats standard 435 MHz transponder downlink on 10 GHz
  - Duplicates downlink for a "virtual" mode V/x from standard transponder uplink

GOLF-TEE SDR Operation Example:

3 Data Down-Link Only Modes

- All provide a CW lock tone to enable better ground locking of the Doppler
- All provide a CW ID stream at about 10 wpm (or other pulse stream)
- 1st Down Link Mode: provides a data channel with a GMSK modulated signal
- 2nd Down Link Mode: provides a data channel with a BPSK modulated signal
- 3rd Down Link Mode: provides a data channel with a OFDM modulated signal

Ray

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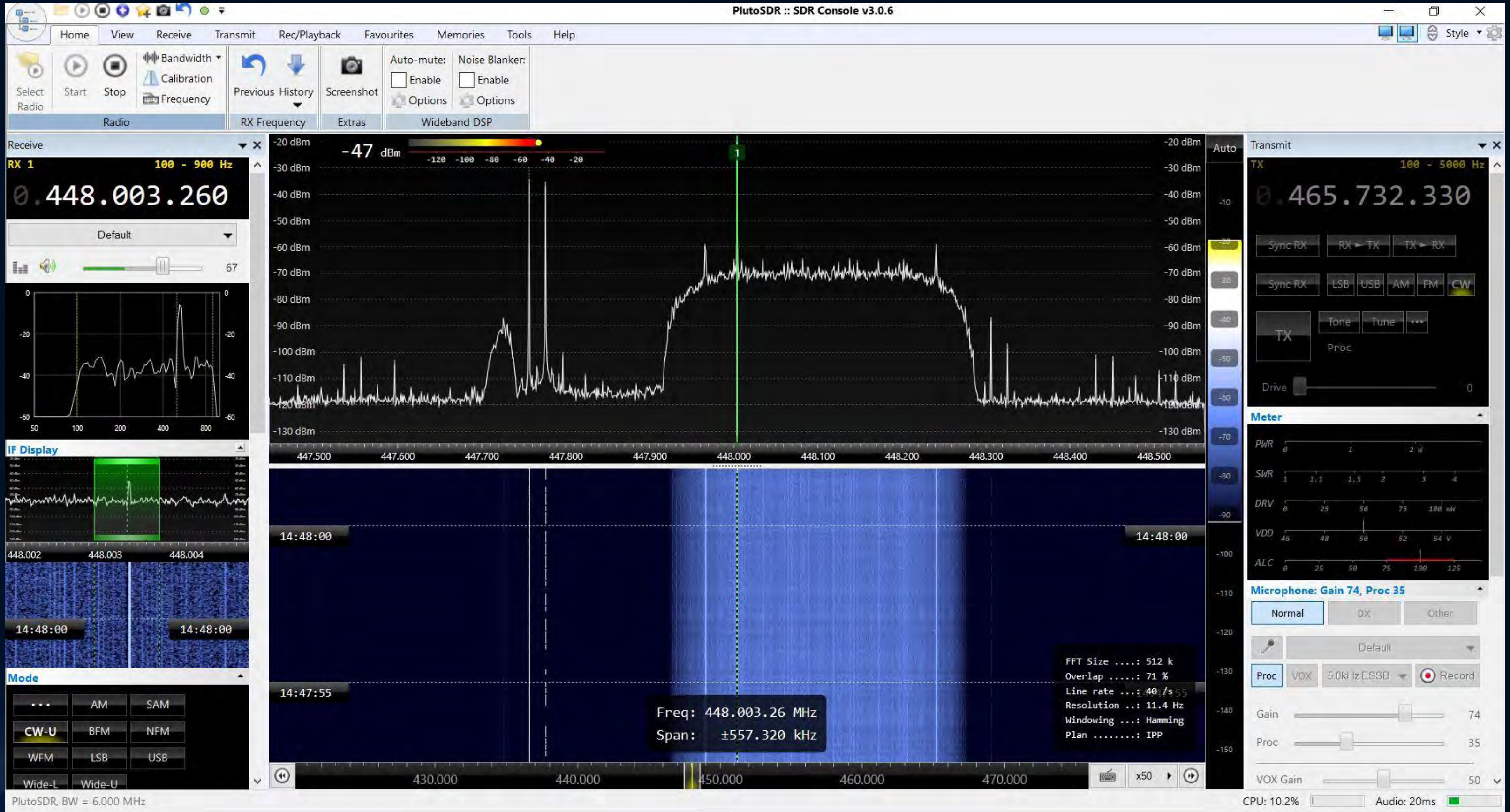
GOLF-TEE SDR Operation Example:

2nd Down Link Mode (BPSK) Beacon

(Closed Test With Frequency Shifted)*



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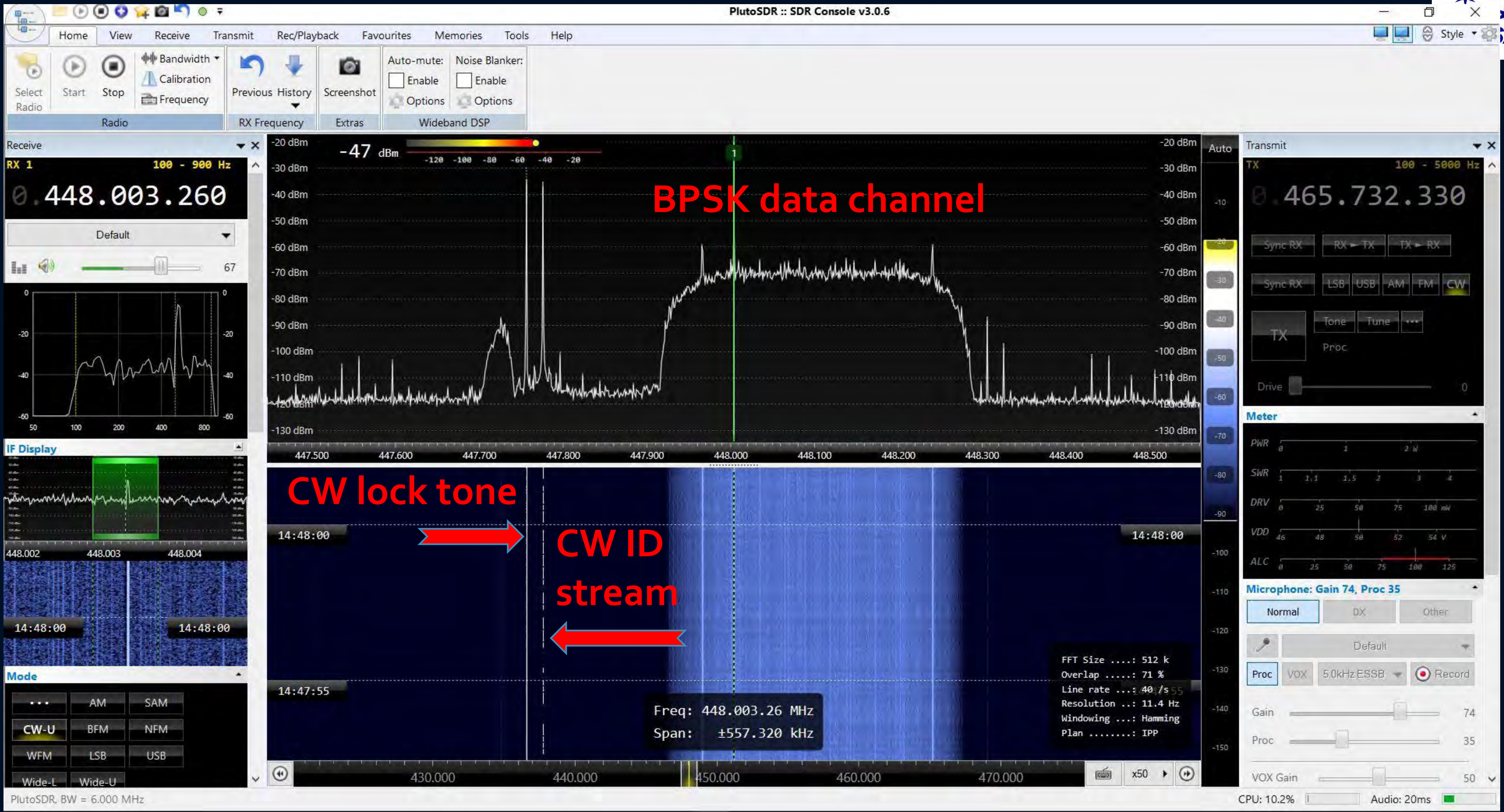
* Used Simon's SDR Console Software and a ADALM Pluto SDR as a receiver


PlutoSDR :: SDR Console v3.0.6
BPSK data channel
CW lock tone
CW ID stream
448.003.260
465.732.330
Freq: 448.003.26 MHz
Span: ±557.320 kHz
PlutoSDR, BW = 6.000 MHz

GOLF-TEE SDR Operation Example:
3 Bent Pipe Modes

- All provide a CW lock tone to enable better ground locking of the Doppler
- All provide a CW ID stream at about 10 wpm (or other pulse stream)

Ray

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GOLF-TEE SDR Operation Example:
3 Bent Pipe Modes

- 1st Bent Pipe Mode: provides 4 , ~18 kHz channels with automatic AGC and squelch per channel. Additionally it provides a 100 kHz bent pipe bandwidth channel

- 2nd Bent Pipe Mode: provides 5 , ~18 kHz channels with automatic AGC and squelch per channel. Additionally it provides a 100 kHz bent pipe bandwidth channel

- 3rd Bent Pipe Mode: provides 19 , ~18 kHz channels with automatic AGC and squelch per channel

Ray

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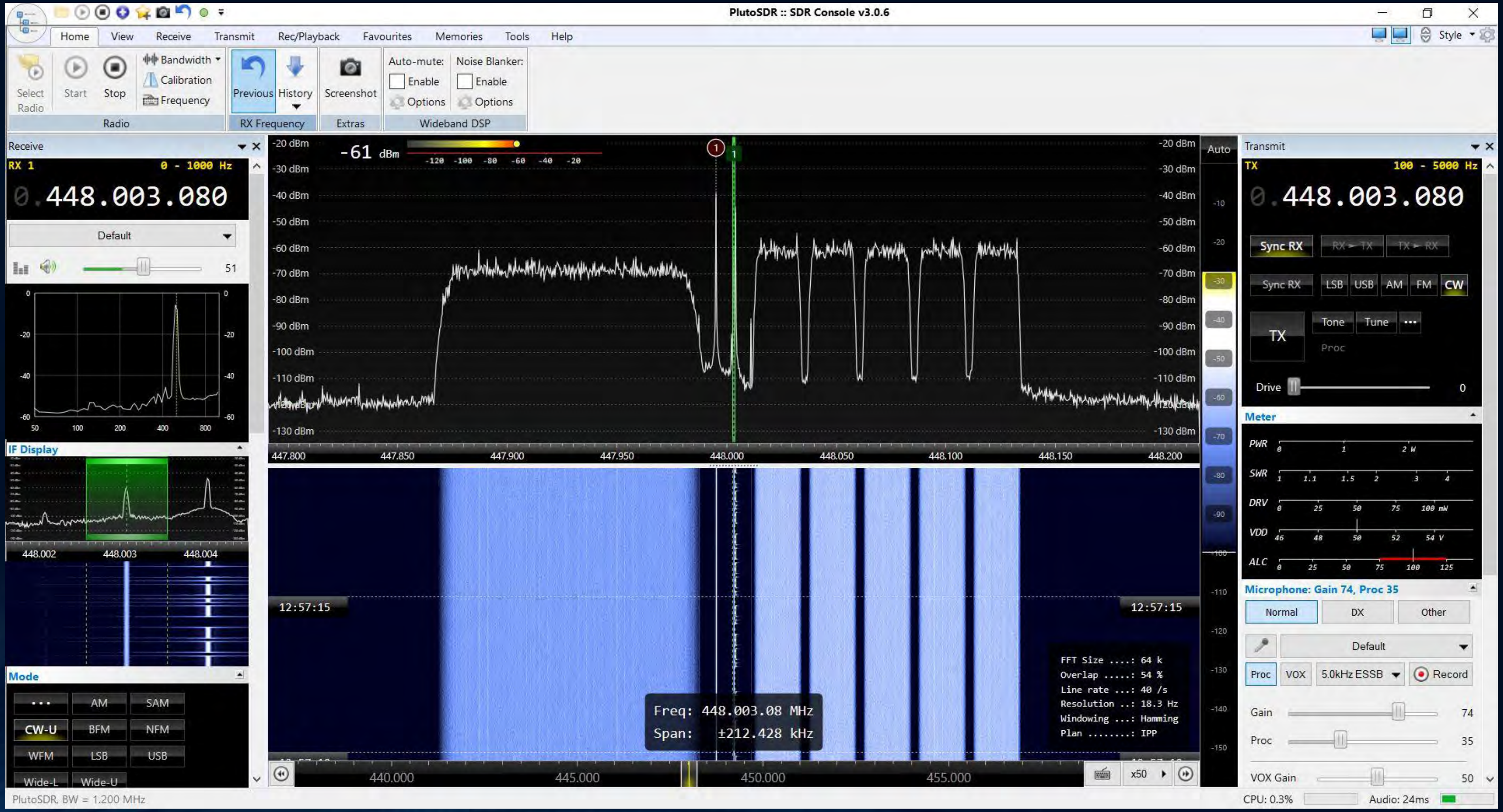
SDR Operation (GOLF-TEE)

2nd Bent Pipe Mode Example

(Closed Test With Frequency Shifted)*

- Channel enable(s) bypassed (squelch signal detect is turned on even when no input) so “Noise of the AGC" is transmitted and seen in the received spectrum.



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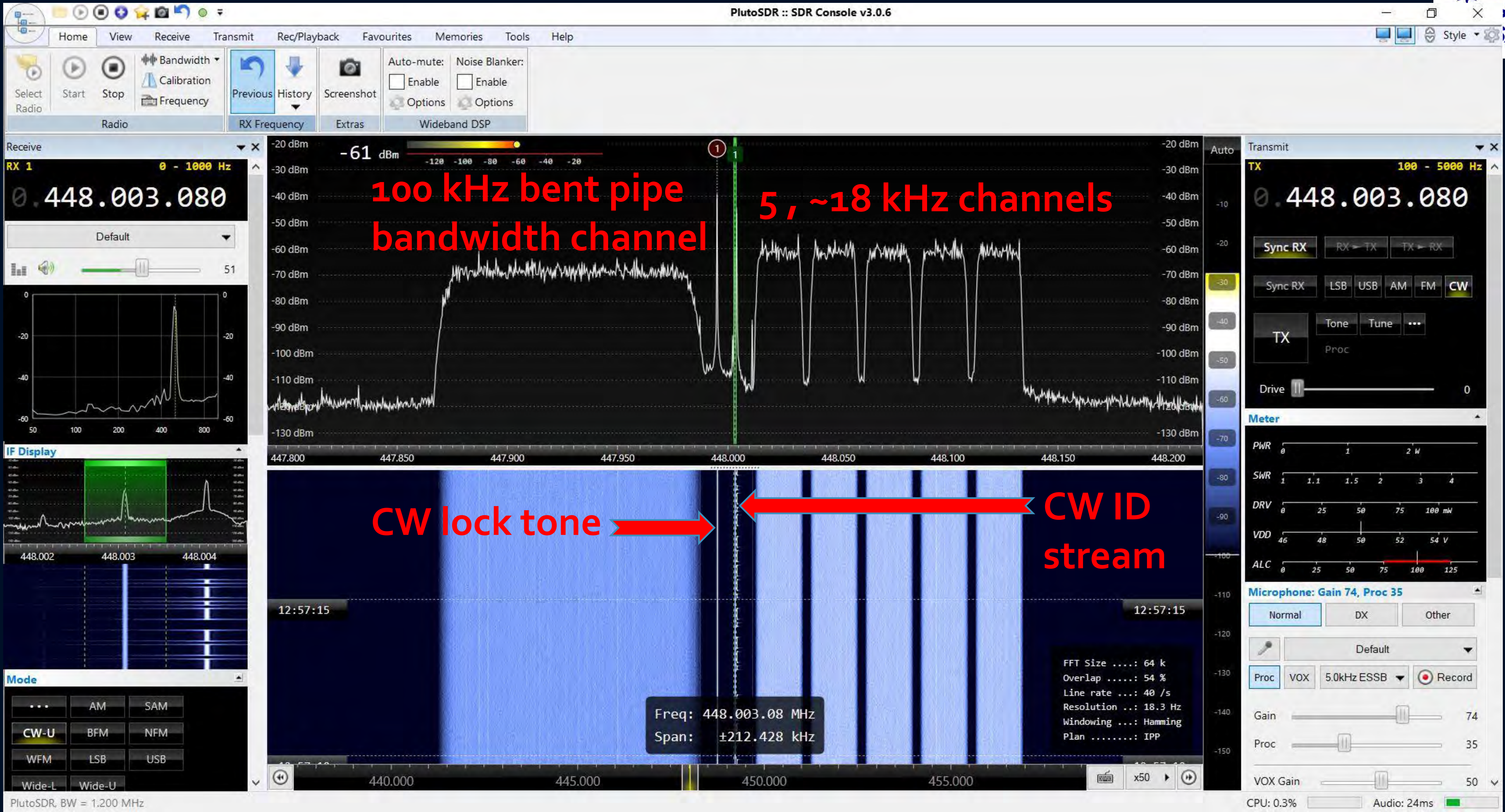
PlutoSDR :: SDR Console v3.0.6
100 kHz bent pipe bandwidth channel
5 , ~18 kHz channels
CW lock tone
CW ID stream
448.003.080
Freq: 448.003.08 MHz
Span: ±212.428 kHz
PlutoSDR, BW = 1.200 MHz

GOLF-TEE / GOLF-1
Ground station

- *Ideas and development welcome!*
- Some considerations
  - Doppler shift at low earth orbit
  - Antenna (pointing or omni?)
  - Output power (probably relatively low?)
  - RF Safety!
  - Receive chain (satellite output TBD)

Microwaves on ARISS Projects: AREx (Amateur Radio Exploration)

INCLUDING LUNAR GATEWAY
BEYOND EARTH ORBIT

Amateur Radio On Human Spaceflight Missions

Slide courtesy of
Frank Bauer WA3HDO

Since 1983, international amateur radio organizations have worked with the space agencies to fly amateur radio and to support educational initiatives on:

Space Shuttle
(SAREX)

ISS
(ARISS)

Mir
(Mirex/SAREX)

AREx on
Lunar Orbiter Gateway

AREx Mark 1 System

- Minimally Capable Educational Outreach System
- Externally mounted "satellite" payload with fixed antennas & cameras attached
  - optional deployable boom for greater visibility
- Simple ground station using COTS components and AREx embedded soft/firmware & data interfaces
- Gateway operations timeframe: early to mid-2022

AREx on
Lunar Orbiter Gateway
AREx Mark 1 System

- “Five and Dime”
  - 5 GHz uplink
  - 10 GHz downlink
- DVB-S2 (supports Voice, Data, SSTV—Pictures, Video)
- Can support radio/technology tech demos and science investigations, similar to AO-40 GPS technology experiment or ISS MarconISSta experiment investigation (see marconissta.com)

AREx on
Lunar Orbiter Gateway

AREx Mark 2 System

- Foundational Educational outreach system
- Fully capable system, internally mounted on Gateway employing RF feedthroughs to pointed 0.6 m dish or flat plate antenna
- Simple ground station using COTS components and AREx embedded soft/firmware & data interfaces
- Gateway operations timeframe: ~2026

AREx on Lunar Orbiter Gateway
AREx Mark 2 System

- S, C, X bands
  - 2.4 GHz uplink
  - 5 GHz uplink (alternative)
  - 10 GHz downlink
- DVB-S2 (supports Voice, Data, SSTV—Pictures, Video)
- Parabolic dish or flat plate antenna, with pointing system
- Can support radio/technology tech demos and science investigations, similar to AO-40 GPS technology experiment or ISS MarconISSta experiment investigation

AREx on
Lunar Orbiter Gateway
Typical ground station

- 1 m pointed dish & LNB
- 75-100 W transmission power
- Minitoune/CODEC software system (see wiki.batc.org.uk)
- Weak signal software interface

AREX OPERATIONAL SCENARIOS

Slide courtesy of
Frank Bauer WA3HDO

X-Band (10.45-10.5 GHz)
C-Band (5650-5670 MHz)

70 cm Band (435-438 MHz)
AREx contingency ops
X-Band (10.45-10.5 GHz)
C-Band (5650-5670 MHz)

Operation Plan:
Nominal: X-band TX Prime; 70 cm Rx only
Contingency: 70 cm TX Prime; X-band TX off

Users
- Schools & General Public (RX only)
- Amateur Radio Operators (RX & TX)
- Experimental/Scientific (RX & TX if licensed)

AREx Gnd Stations
- Cmd
- TLM
- Contingency

Bochum, GAVRT, & Goonhilly

Telebridge Network

BATC Server RX Distribution

AREX OPERATIONAL SEGMENTS

Slide courtesy of
Frank Bauer WA3HDO

Space Segment
Crew Tended | Autonomous

User Segment
Educational Outreach | Amateur Ops | Experimental Scientific

Operations Control Segment
Nominal | Contingency Ops

AREx
Other project possibilities

- Lunar orbiting amateur radio satellites
- Lunar lander amateur radio satellites

(May come about prior to and instead of Gateway, depending on funding politics)

2020 AMSAT Space Symposium, October 16-18 Minneapolis-St Paul MN

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Thank you for the opportunity to share

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OCCASIONAL LIVE STREAMS ABOUT AMSAT ENGINEERING TWITCH.TV/NØJY